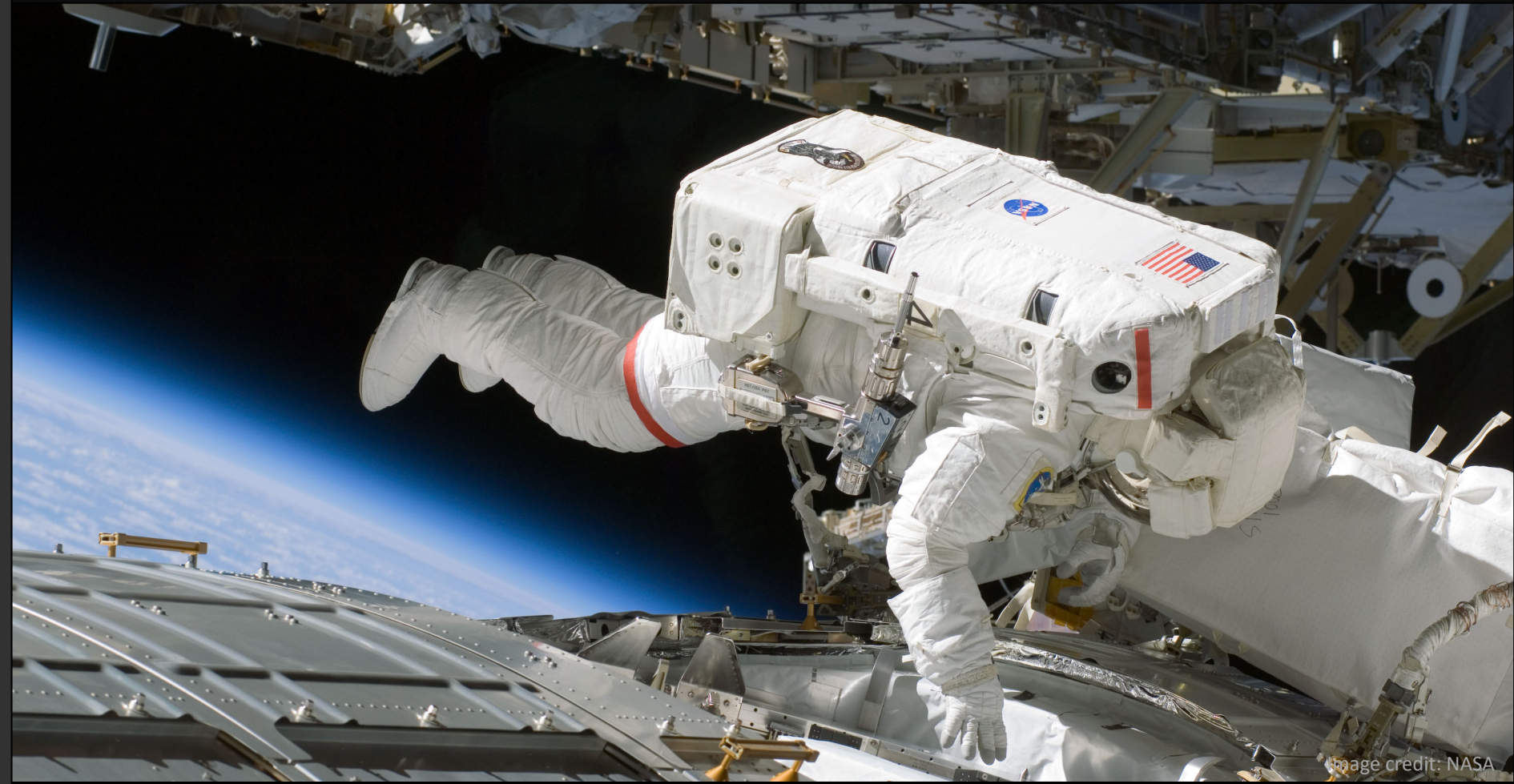


Orbital and Intracranial Effects of Microgravity: 3T MRI Findings



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Disclosures



Neither I nor my immediate family members have a financial relationship with a commercial organization that may have a direct or indirect interest in the content.

Image credit: NASA

Goals and Objectives

1. To briefly describe a newly discovered clinical entity related to space flight.
2. To describe normal anatomy and pathologic changes of the optic nerve, posterior globe, optic nerve sheath and pituitary gland related to exposure to microgravity.
3. To correlate imaging findings with known signs of intracranial hypertension.

Target Audience

1. Radiologists, neurologists, neuro-ophthalmologists and space medicine physicians.
2. All those who aspire to future space travel.

Introduction

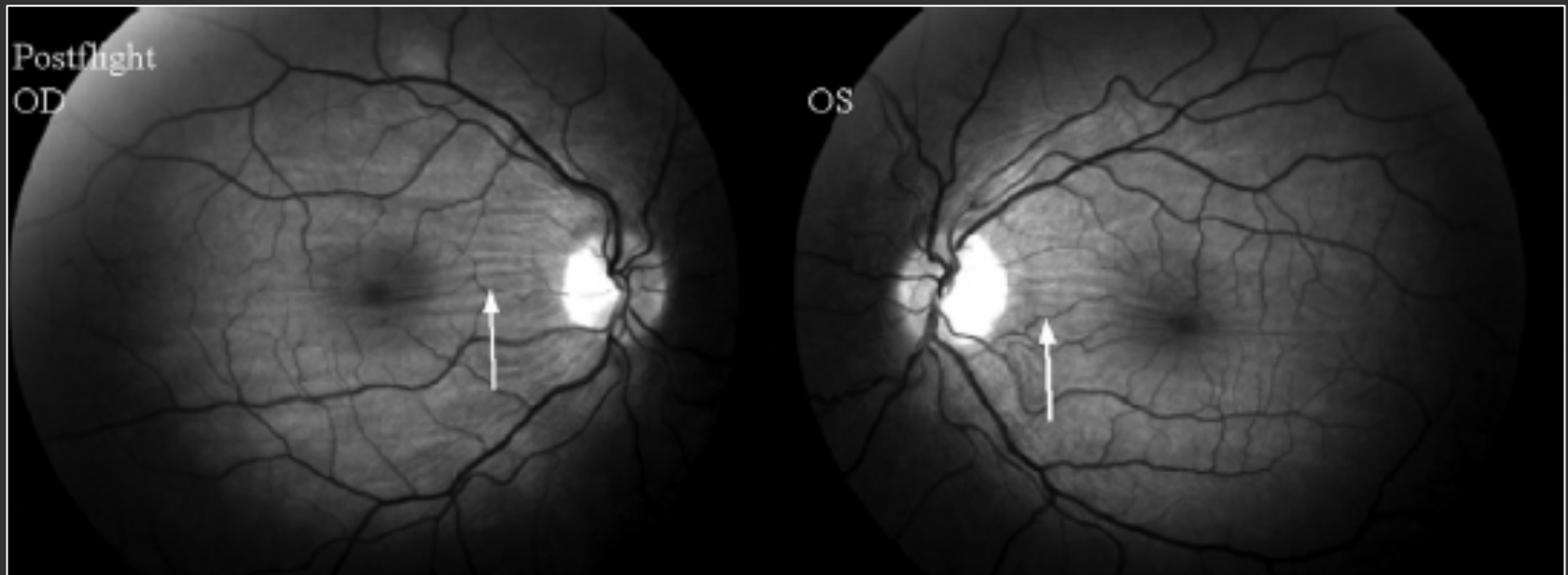
- The altitude of the International Space Station (ISS) varies between 200-250 miles.
- Gravity at these altitudes is approximately 88% of that on the ground (1G).
- The tangential velocity of the orbital motion balances these residual g-forces to create the state of weightlessness (0G).



Physiology

- Human physiology has evolved with the ambient gravitational force of earth (1G).
- Gravity creates hydrostatic pressure which pools venous blood in the lower extremities.
- Loss of a net gravitation force results in cephalad fluid shifts.
- Cephalad fluid shifts results in facial congestion and jugular vein distension.

Mader et. al. (1) (2011) retrospectively reviewed over 300 questionnaires regarding in-flight vision changes and found that 29% of short duration and 60% of long duration space flight astronauts experienced visual degradation. Clinical examinations on the most severe cases (n=7) revealed combinations of optic disc edema, cotton wool spots, choroidal folds and nerve fiber layer thickening.



CHOROIDAL FOLDS (post-flight astronaut): Note multiple linear bands on a red free fundus photograph (white arrows) compatible with choroidal folds (courtesy of Elsevier LTD)(1). Choroidal folds are clinically manifested by distorted vision such as wavy appearances of straight lines (metamorphopsia).

Hypothesis

Can microgravity raise intracranial pressure via venous congestion and cephalad fluid shifts resulting in visual degradation?

To further characterize findings seen on neuro-ophthalmologic examination and to identify potential comorbidities, high resolution MR imaging of orbits and brain at 3 Tesla was requested to evaluate astronauts exposed to microgravity.



Definitions and Anatomy

Short Duration < 30 Days = Space Shuttle



Image credit: NASA

Long Duration > 30 Days = ISS

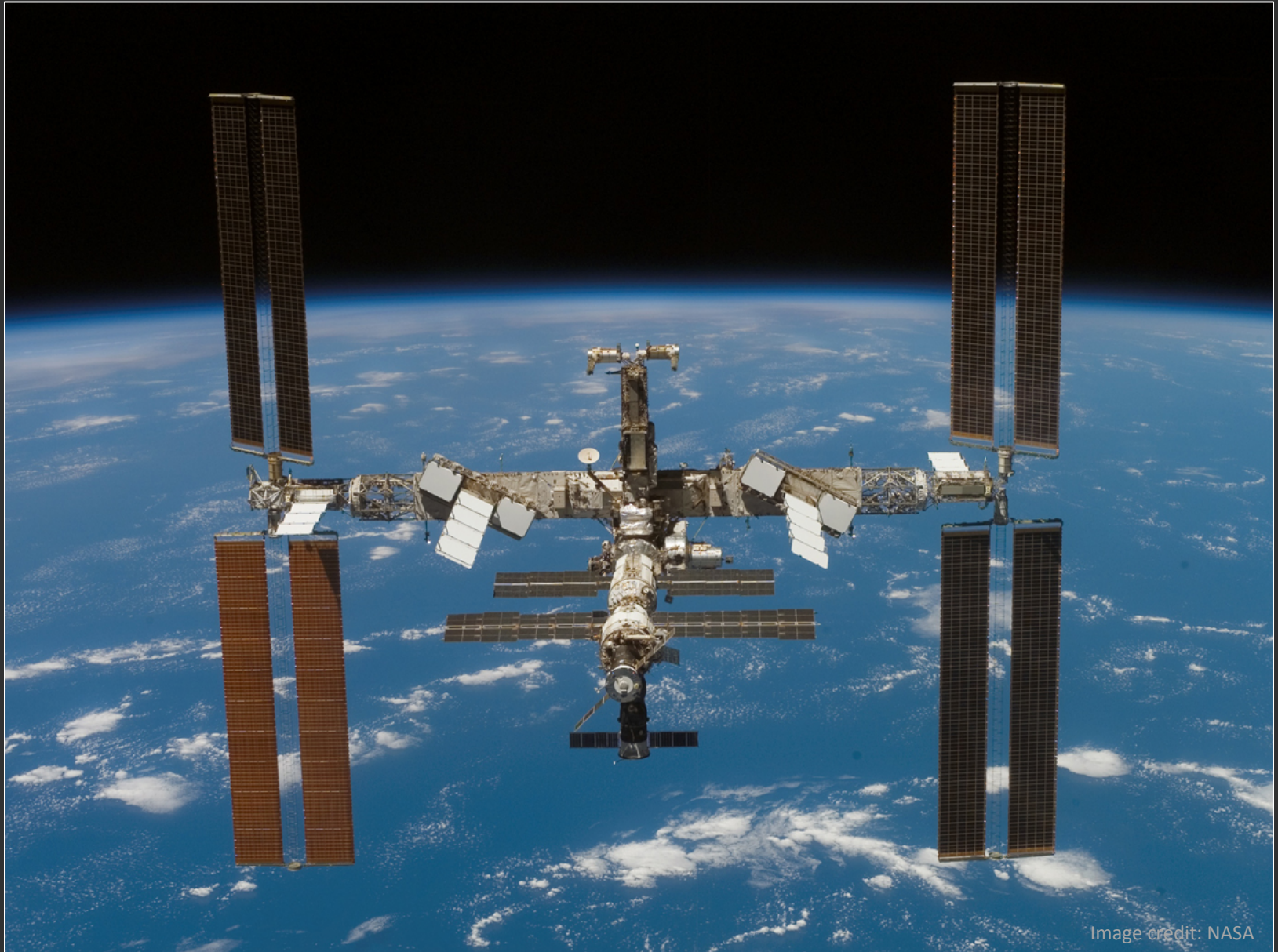
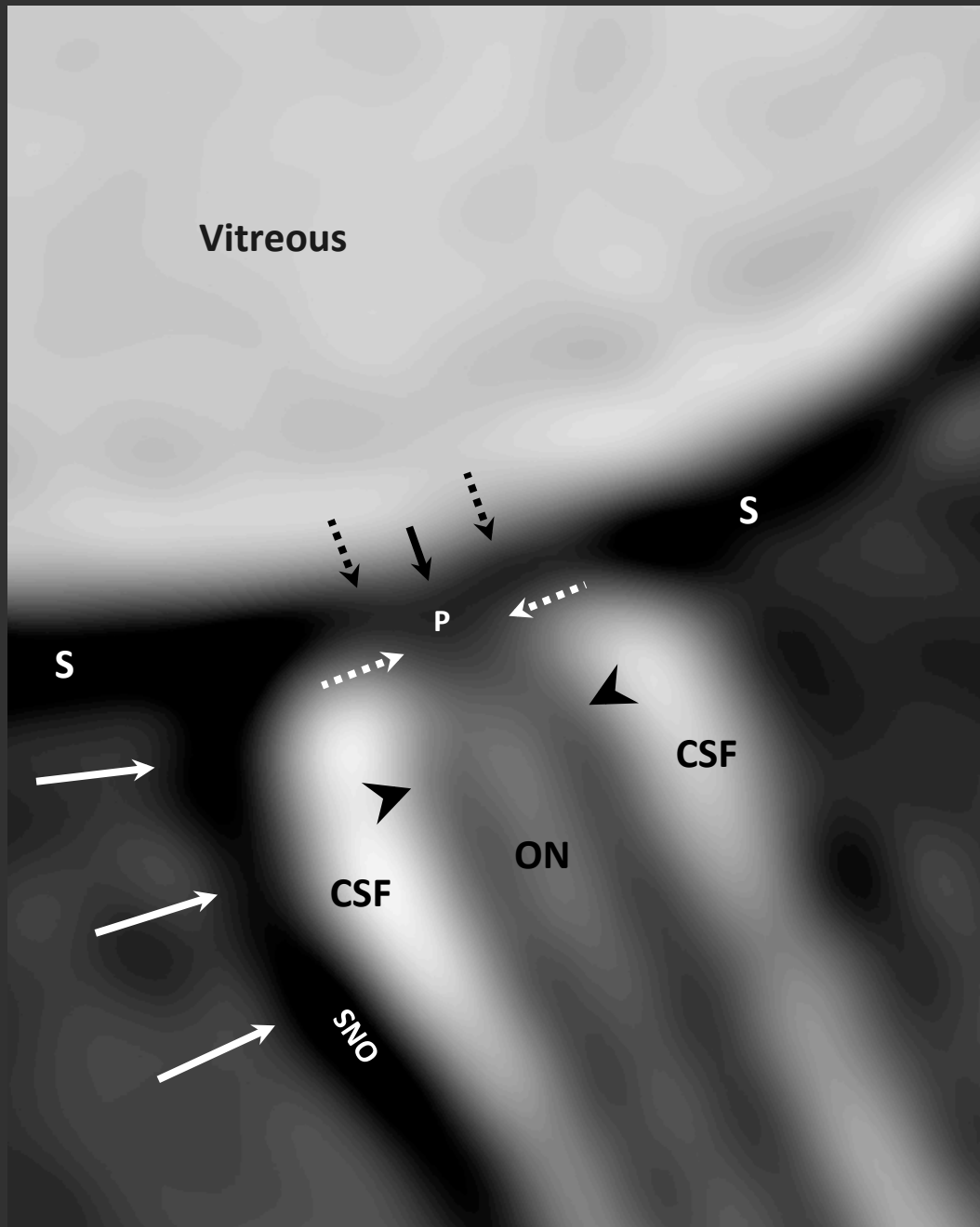
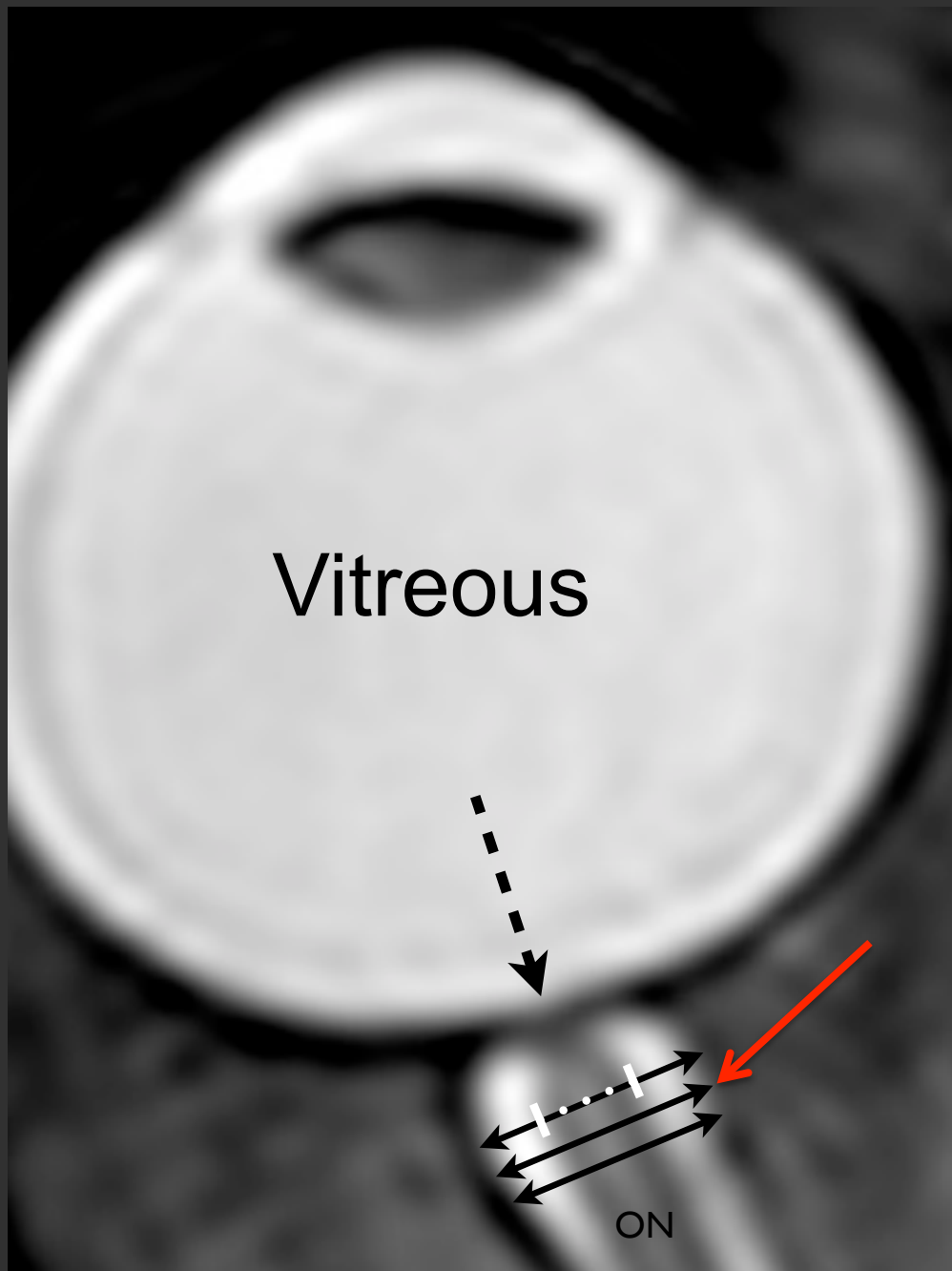


Image credit: NASA



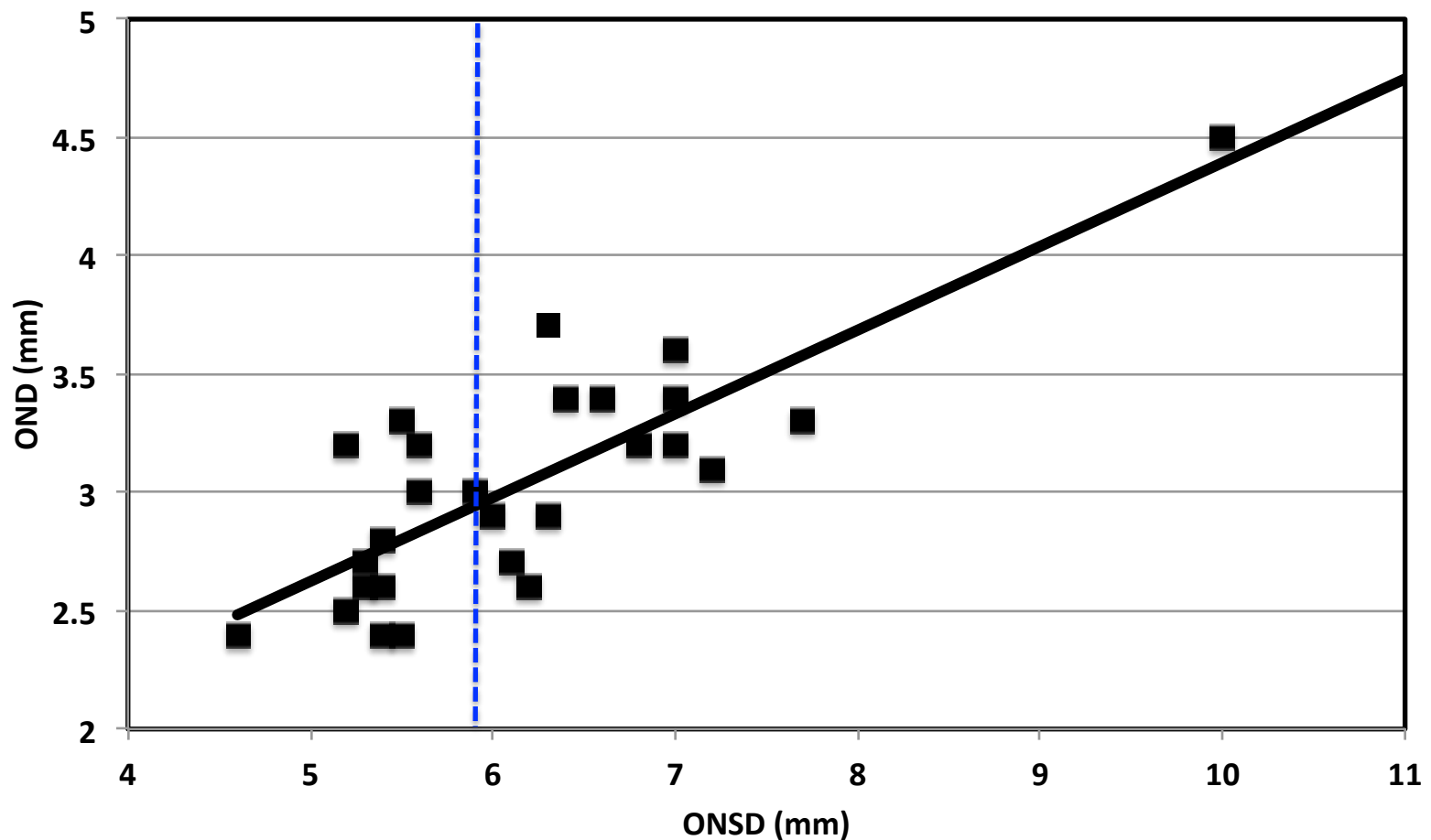
HIGH RESOLUTION 3D T2 AXIAL IMAGE THROUGH THE GLOBE: The white arrows represent the bulbar portion of the optic nerve sheath (ONS), which is the region of greatest distention when subjected to increased intracranial pressure. The dashed black arrows represent the annular ridge of the optic papilla (p). The solid black arrow represents the physiologic cup of the optic papilla. The dashed white arrows represent the laminar portion of the optic nerve. The arrowheads represent the beginning of the myelinated optic nerve (ON) referred to as the retrolaminar optic nerve. S = Sclera.



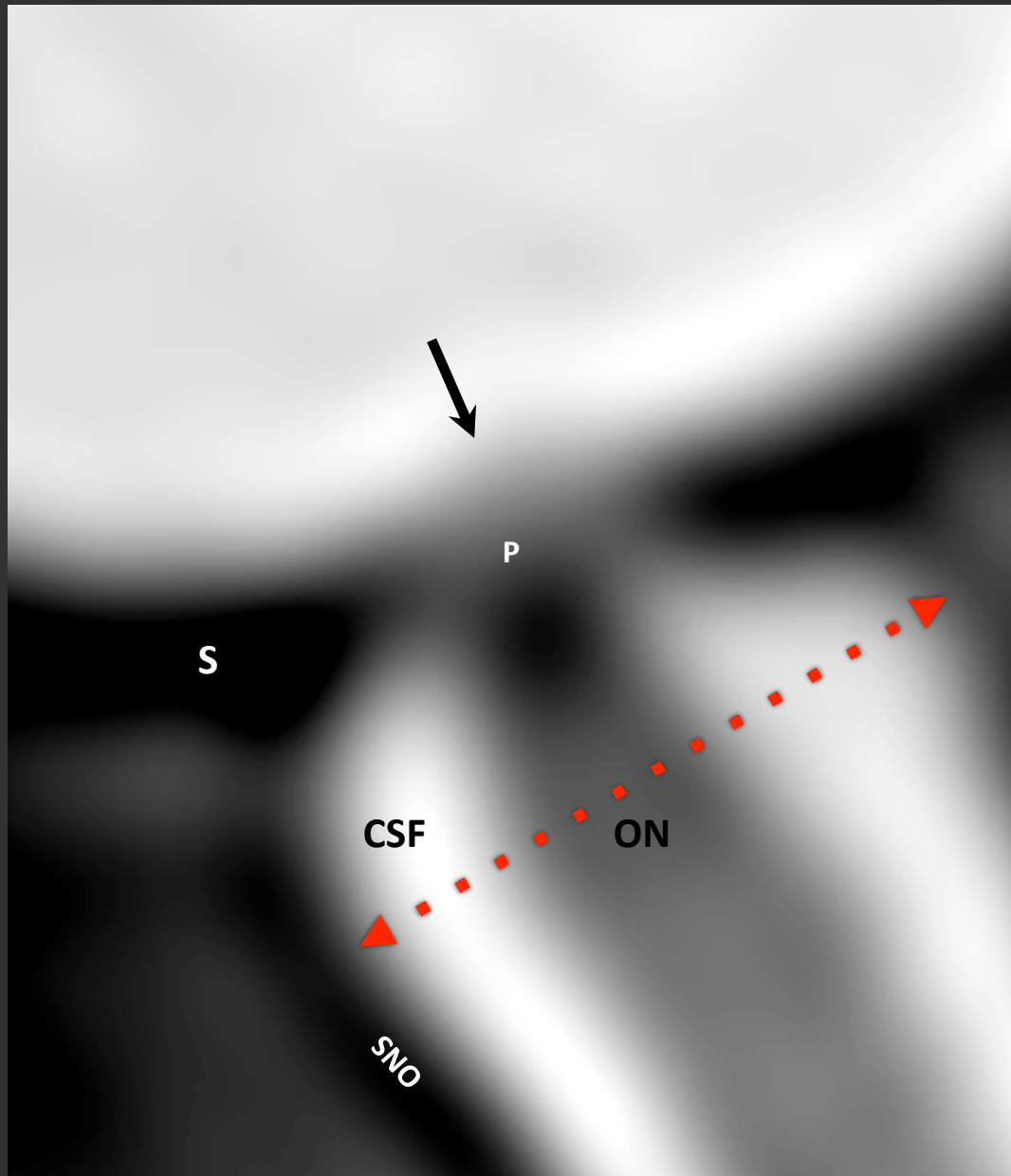
HIGH RESOLUTION 3D T2 AXIAL IMAGE THROUGH THE GLOBE: The subarachnoid space surrounding the optic nerve is in direct communication with the intracranial subarachnoid space. Increases in intracranial pressure will raise cerebral spinal fluid (CSF) pressure in the optic nerve sheath and distend the sheath. An optic nerve sheath diameter greater than 5.8 mm, 3 mm posterior to the globe (red arrow) is considered indicative of intracranial hypertension (2). The dashed arrow represents the physiologic cup of the optic papilla. The dashed white bar indicates the optic nerve diameter at 2 mm posterior to the globe where optic nerve (ON) diameters were measured.

MRI Findings Associated with Microgravity

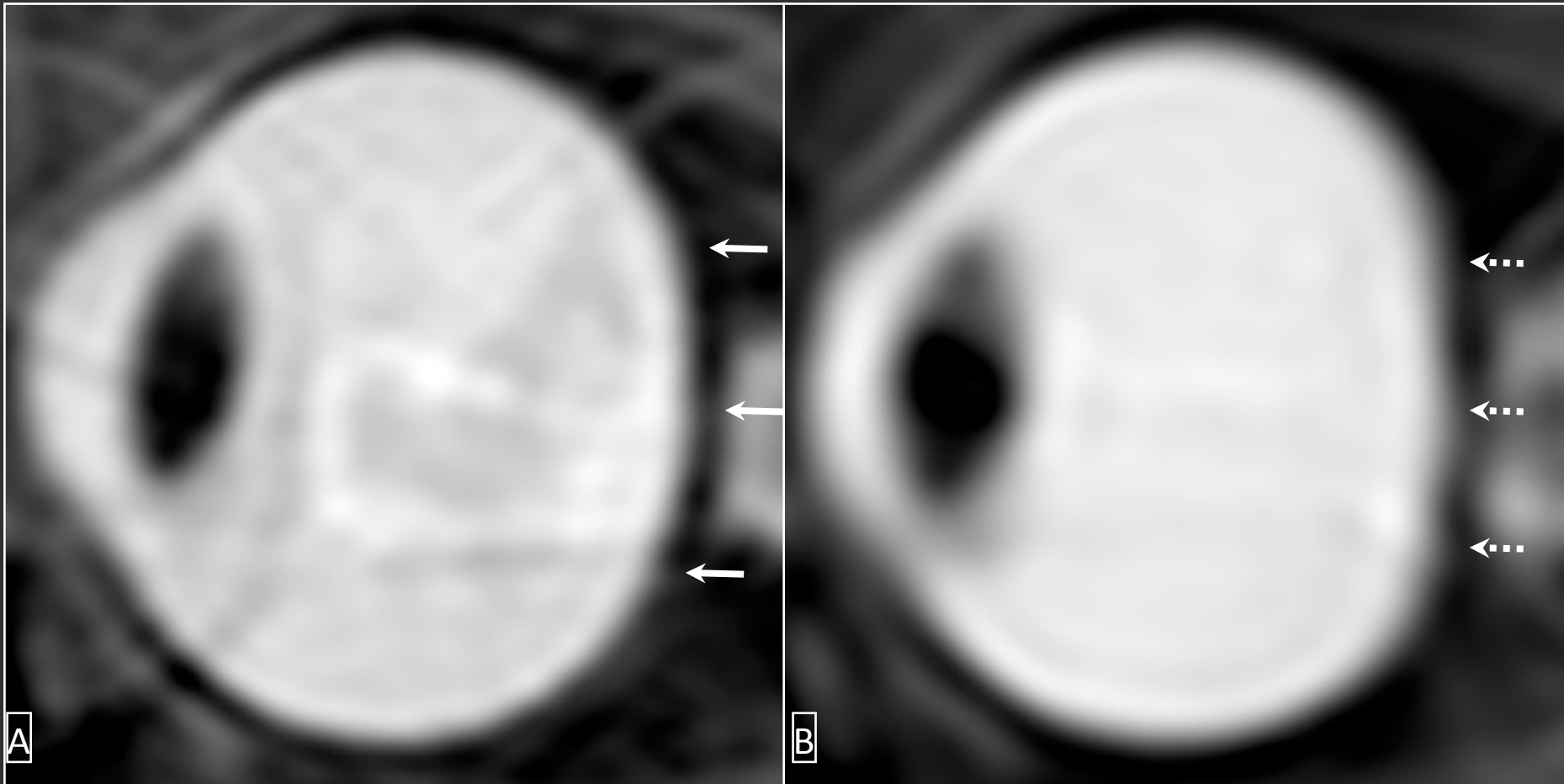
- Optic nerve sheath distension
- Optic disc edema
- Posterior Globe Flattening
- Tortuosity of the optic nerve sheath
- Moderate Concavity of the pituitary gland with posterior displacement of the stalk



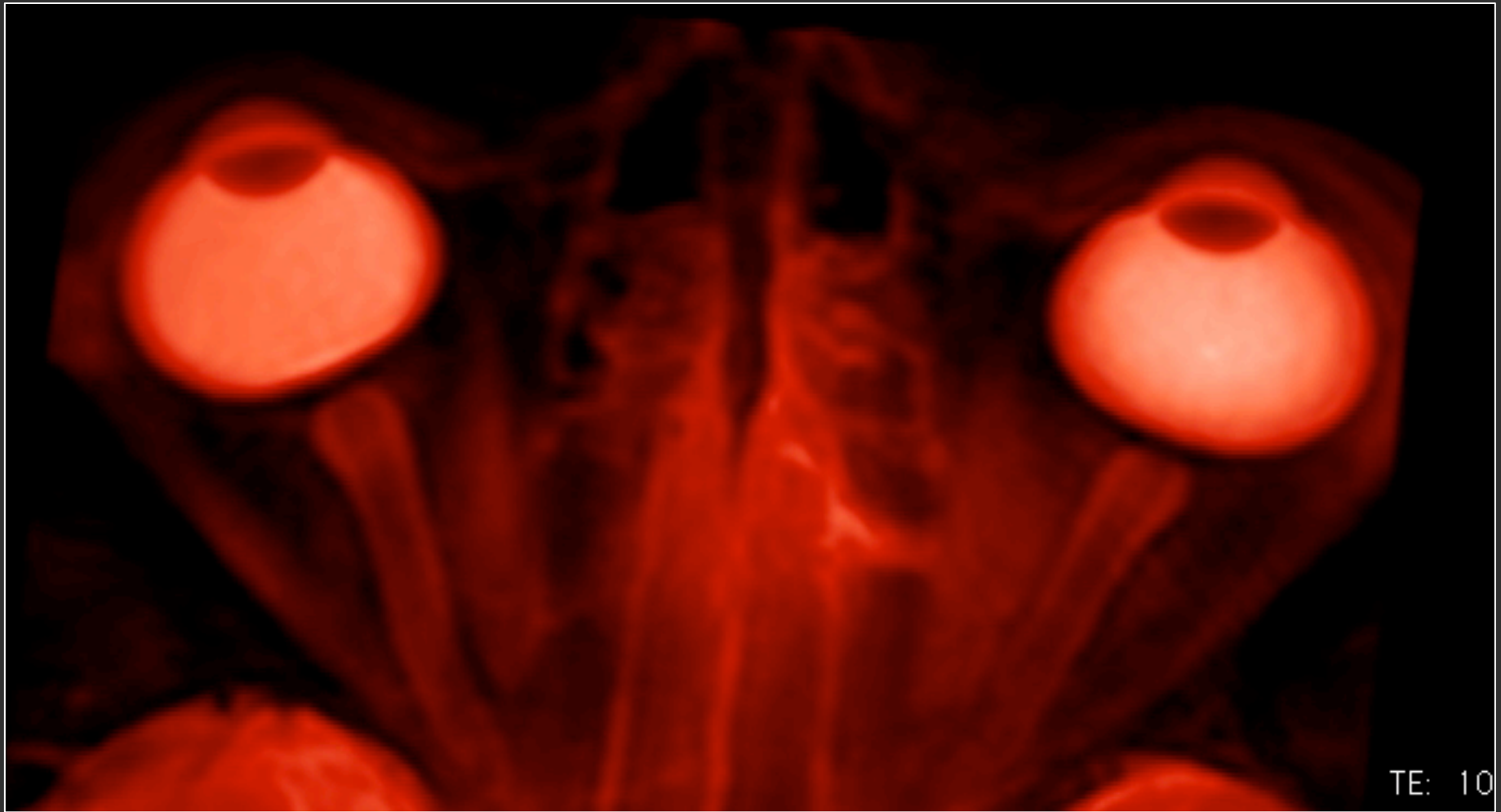
OPTIC NERVE SHEATH DISTENSION: Plot of Optic Nerve Sheath Diameter (ONSD) versus Optic Nerve Diameter (OND) in 27 astronauts exposed to microgravity demonstrating a linear relationship between ONSD (@3mm posterior to sclera) and OND (@ 2mm posterior to sclera). Abnormal ONSD (> 5.8 mm) is indicative of intracranial hypertension (blue line = 5.8 mm). Note that there are at least 14/27 astronauts with abnormal ONSD. Normal OND = 2.9 ± 0.5 mm (3); 3.2 ± 0.4 mm (4).



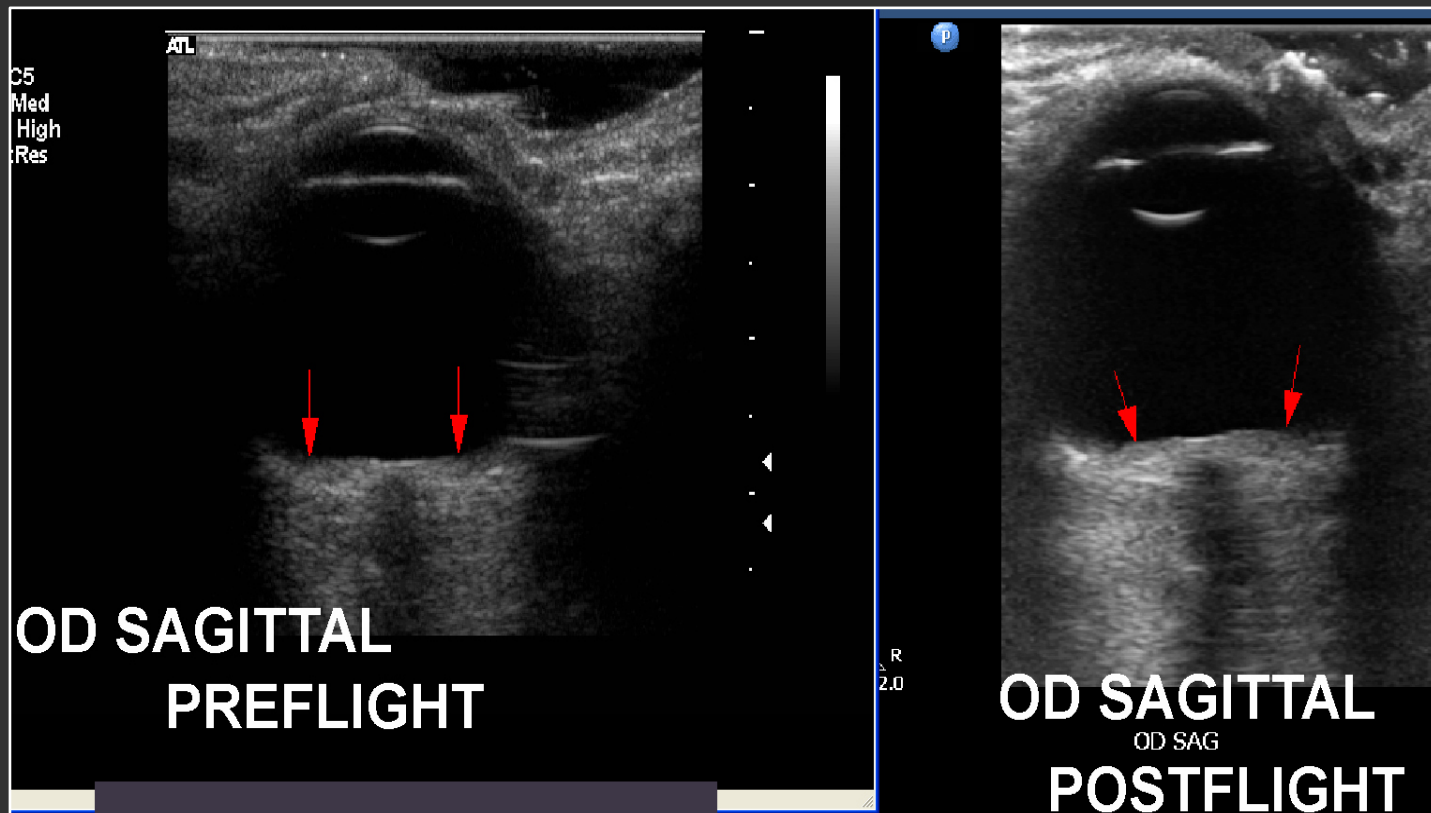
OPTIC DISC EDEMA: Optic disc edema is a non-specific imaging finding. It is the cardinal sign of idiopathic intracranial hypertension when associated with intracranial hypertension. Note protrusion of the optic papilla (p) (black arrow) with loss of the physiologic cup and distension of the ONS (red arrow) on this astronaut with long duration microgravity exposure. S = Sclera; CSF = subarachoid space surrounding the optic nerve; ON = optic nerve; ONS = optic nerve sheath.



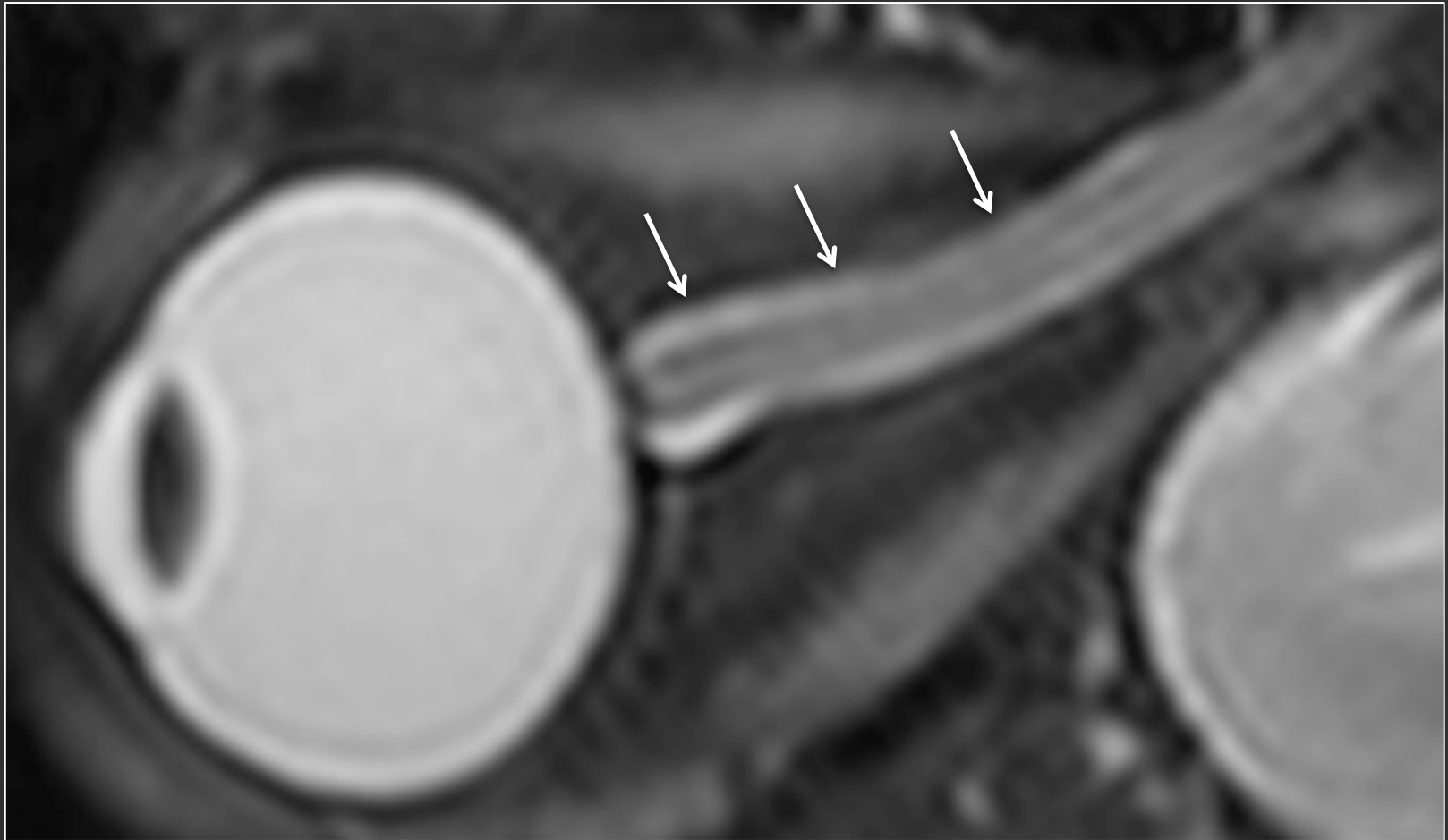
Posterior Globe Flattening: (A). Note the normal convexity of the posterior globe before a repeat mission (solid white arrows). (B) Note the flattening of the posterior globe after a long duration mission (dashed white arrows). The exact mechanism by which microgravity causes flattening of the globe is not well understood. Flattening of the posterior globe is found in patients with idiopathic intracranial hypertension with high specificity (4).



Example of bilateral posterior globe flattening utilizing a maximum intensity pixel projection.

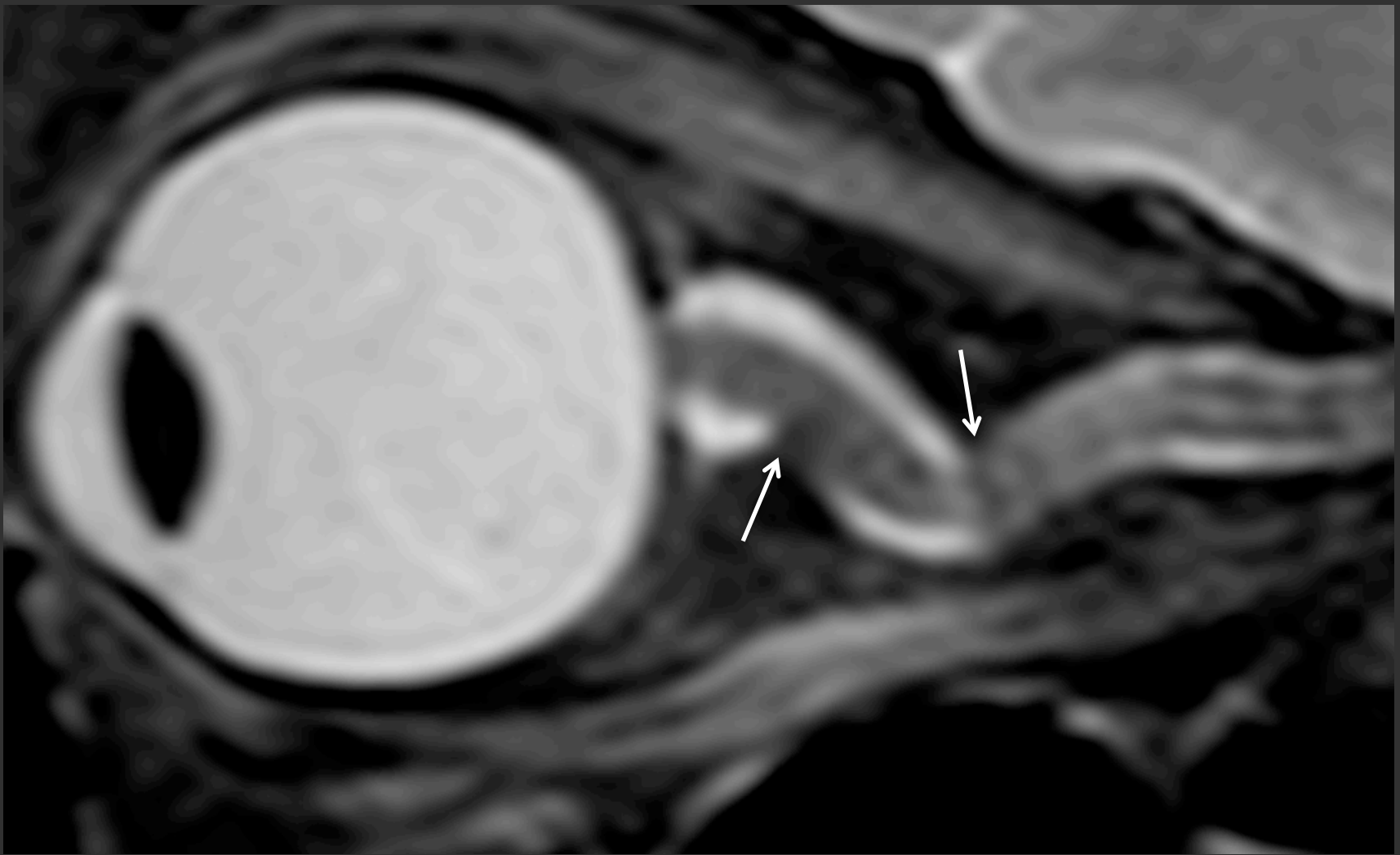


HIGH RESOLUTION ORBITAL ULTRASOUND: Orbital ultrasound is a technique currently being deployed on the ISS for monitoring changes in optic nerve sheath diameter and morphologic changes of the posterior globe while in the microgravity environment. In addition, pre-flight and post-flight studies are also performed. Note increased posterior globe flattening post-flight (red arrows).

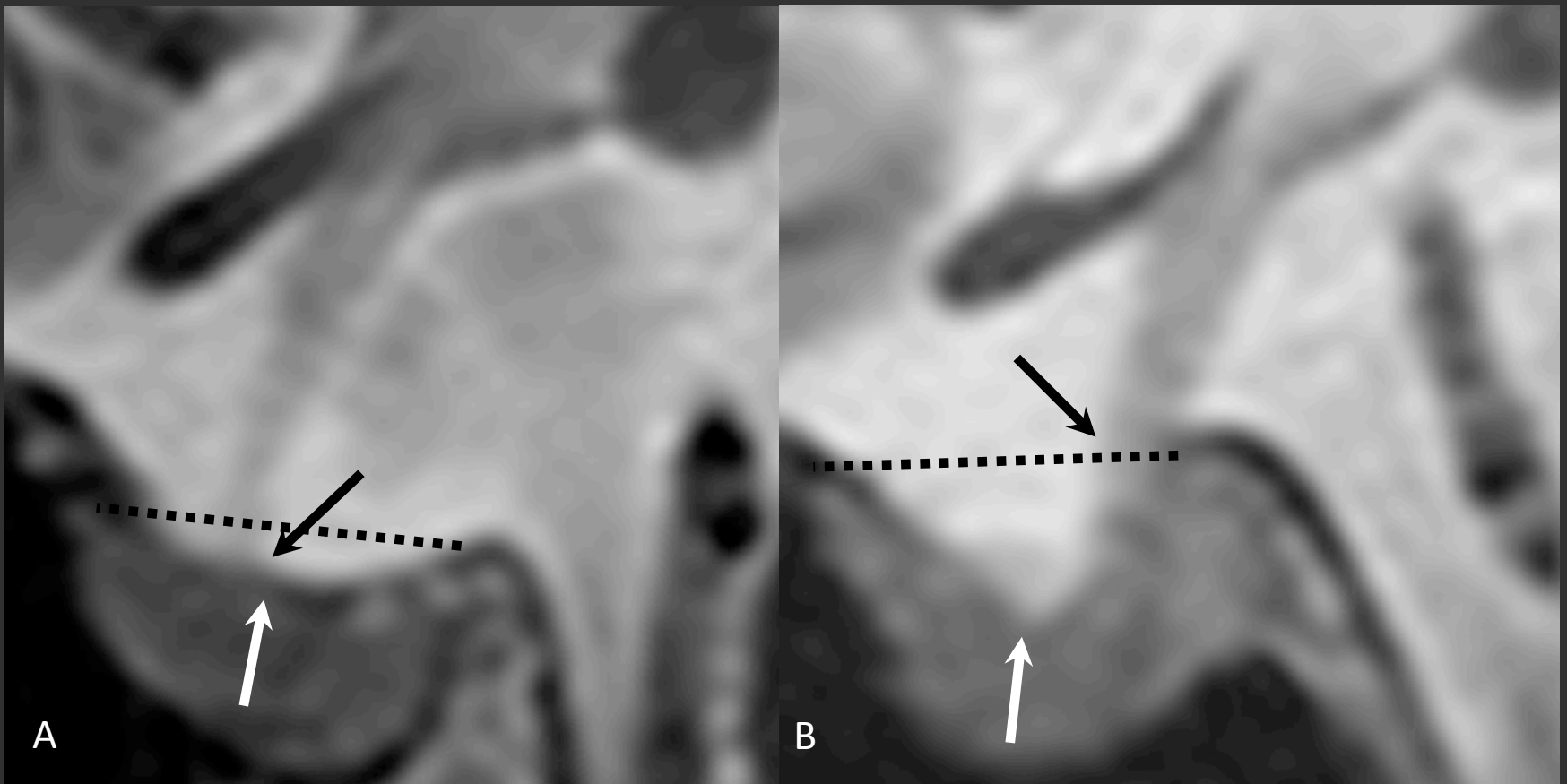


NORMAL MORPHOLOGY OF THE OPTIC NERVE SHEATH:

Note the mild redundancy of the optic nerve sheath (arrows) which is within normal limits and allows for unrestrained motion of the globe.



OPTIC NERVE SHEATH TORTUOSITY WITH KINK: Note flattening of the posterior globe (dashed arrows) and the acute angles in the optic nerve sheath (solid arrows). The exact mechanism by which microgravity causes optic nerve sheath tortuosity is not well understood but it is only seen with abnormal optic sheath diameters indicative of increased intracranial pressure.



MODERATE CONCAVITY OF THE PITUITARY GLAND AND POSTERIOR DISPLACEMENT OF THE STALK: (A). The normal pituitary gland demonstrates upward convexity of the dome (white arrow) and midline position of the stalk (black arrow). (B) Note the moderate concavity ($> 33\%$ of the loss of height of the pituitary gland (white arrow) relative to the height of the pituitary fossa (dashed line) and posterior displacement of the pituitary stalk (black arrow) after long duration mission. These findings are believed to be related to prolapse of an arachnoid diverticulum through the diaphragma sella due to elevated CSF pressures. This finding has been shown to have high specificity for idiopathic intracranial hypertension (5).

Cumulative Lifetime Exposure to Microgravity (days)	Total Number of Astronauts	Posterior Globe Flattening	Optic Nerve Sheath Kink	Optic Disc Protrusion	ONSD \geq 5.9mm	Moderate or greater Pituitary Concavity
<30 (short)	12	1 (4%)	1 (4%)	0	5 (19%)	0
\geq 30 (long)	15	6 (22%)	3 (11%)	4 (15%)	9 (33%)	3 (11%)

CUMULATIVE LIFETIME EXPOSURE TO MICROGRAVITY VERSUS IMAGING ABNORMALITY: Imaging abnormalities are seen with both short and long term exposure. Optic disc protrusion and pituitary changes were however, only seen with long duration exposure indicating severity increases with exposure time. In addition, the percentage of abnormal to normal findings increases with increasing duration of exposure.

Conclusion



Visual degradation in astronauts exposed to microgravity is a newly recognized phenomenon which could potentially limit long duration space travel. The etiology of the visual changes is not well understood however, the constellation of imaging findings detected by MRI suggests intracranial hypertension plays an important role. The variable biologic response between astronauts requires further research into identification of potential risk factors and prevention of long term sequelae.

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7. Images from space-images.com and <http://grin.hq.nasa.gov> (public domain)



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Image credit: NASA

